

## MARS GLOBAL SURVEYOR: THE FIRST YEAR AT MARS

by

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### ABSTRACT

Mars Global Surveyor arrived at Mars on September 11, 1997, to begin a short period of orbit transformation and then to embark upon two years of intensive mapping of the Martian surface and atmospheric observations. The period of aerobraking was to have taken four months with mapping to have started on March 15, 1998. The discovery of the effects of previously unknown damage to the spacecraft's solar array support assembly caused the flight team to reduce the intensity of aerobraking, thus precluding the mapping mission as originally planned. This paper discusses the flight and ground support events of the first year at Mars with an assessment of the strategic and tactical aerobraking planning. It examines the effect of the reduced aerobraking progress and the new mission design that resulted. The opportunities for additional science observations during the extended aerobraking period are discussed.

### INTRODUCTION

The Mars Global Surveyor (MGS) spacecraft arrived at Mars, after a 10-month cruise from Earth, on September 11, 1997, ready to begin acquiring a new understanding of the Red Planet.<sup>1</sup> The mission plan called for 4-months of orbit period reduction and circularization using a technique called aerobraking.

Aerobraking would require the spacecraft's periapsis altitude to be reduced so that at each of

slightly more than 400 closest approaches to the planet the spacecraft would fly through the upper reaches of the Martian atmosphere for a few minutes. The resultant drag on the extended solar panels would slow the spacecraft's orbital velocity with each pass through the atmosphere. Repeated slowing would eventually reduced the 45-hour duration elliptical orbit to a 2-hour duration circular orbit.

With the exception of one short period of safe-mode operations, the Earth to Mars cruise period was unremarkable.

After fifteen aerobraking orbits it became clear that one of the solar panels wasn't holding up to the drag forces on it as expected. Three orbits later, a hiatus from aerobraking was taken to evaluate the situation, and upon determining that there was a structural degradation associated with the panel's attachment structure, the remaining aerobraking activity was modified to reduce the stress on the panel. The resulting reduction in the intensity of aerobraking would require an additional year of aerobraking to reach the desired 2-hour orbital condition. The added time before mapping could start, plus the decision to acquire science data as an adjunct to each drag pass, enabled a nearly seventeen month period of "bonus" science acquisition.

In its new mission plan, orbital geometry considerations required breaking the additional operationally intense aerobraking time into two separate periods with an intermediate period of a relative quiet science data acquisition operations.

The spacecraft and its science payload performed well during their first year at Mars. The "bonus" science acquisition opportunities yielded several

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new insights into our understanding of the planet and its atmosphere.

### ORIGINAL MISSION PLAN

The original MGS mission plan was based on aerobraking as rapidly as possible so as to expedite the beginning of mapping operations in case there was a spacecraft lifetime issue.<sup>2</sup> The aerobraking intensity was, by design, limited by the maximum amount of aerodynamic heating that could be tolerated by the design and implementation of the solar panels which provided the drag surface. A dynamic pressure corridor of 0.58 to 0.68 N/m<sup>2</sup> controlled the aerobraking strategy.

The original aerobraking design was built around using the back surface of the solar panels as the drag surface in order to limit the heating and potential atmospheric abrasion on the solar cells. This plan was challenged when it was discovered just after launch that the -Y side solar panel had not latch and was, in fact, an indicated 20 degrees from its fully deployed position. Analysis indicated that a small lever arm had broken during deployment and probably become lodged in the hinge joint between the inboard panel section and the yoke structure that connects the panel to its electro-mechanical actuator. When the lever arm broke off, the panel began an undamped motion that would later be determined to have exerted high force on portions of the solar array support structure. Without the latch to hold the panel in position, the aerodynamic forces on the back side of the panel would push the panel into the main spacecraft electronics module and in the process significantly reduce the aerodynamic surface thus driving the spacecraft, during aerobraking, into an unstable attitude. The solution was to risk using the front or solar cell side of the panel as the drag surface. Additional thermal tests of the solar panel's qualification unit were conducted to validate the acceptability of this solution. The aerodynamic force would then be transmitted into the lever arm that was trapped in the hinge joint as the forces tended to push the panel into its fully deployed position. It was speculated that eventually the lever arm might be crushed into the honeycomb material of the solar panel or the yoke structure, clearing the obstruction altogether, and the panel might then latch normally.

Aerobraking would continue for four months until the orbital period had been reduced to 2

hours, the orbit was circular, and the descending node (where the spacecraft crosses the equator of Mars) was at 2 PM local solar time. A period of gravity calibration with no spacecraft activity followed by nadir pointing of the science instrument and deployment of the high gain antenna would enable routine mapping operations to start in mid-March 1998.

MGS is designed to conduct mapping operations with the instruments continuously pointed at the planet while the solar panels articulate to remain pointed at the sun, and the high gain antenna is articulated to point at the Earth. Science data is acquired continuously, stored in the spacecraft's solid state recorders, and playback back to Earth during one continuous 10-hour Deep Space Network 34 meter station tracking pass (during the Earth viewing portion of five contiguous spacecraft orbits) each day.

Mapping was planned to continue for 687 Earth days or one Mars year in order to fulfill the mission's science objectives for viewing Mars over a full annual cycle.

### MARS ORBIT INSERTION

MGS has been in orbit around Mars since September 11, 1997. It was placed into a 45 hour elliptical orbit with a near perfect orbit insertion maneuver to slow its cruise speed by 973 m/s to allow it to be captured by Mars' gravity. The orbital period was only 45 seconds short of its nominal target! The science instruments were turned on two days later in the second orbit of the planet to begin a short period a contingency science acquisition before the beginning of the months long aerobraking activity.

As a result of the -Y solar panel structural weakness, several changes were instituted in the orbit insertion strategy to provide more margin. These changes included reducing the capture orbit period from 48 to 45 hours, reducing the capture orbit periapsis from 313 to 250 km, and reducing the time of the first aerobraking steps into the atmosphere from 9 to 7 days. In addition, the walk-in into the atmosphere would be accelerated by reducing the time between aerobraking maneuvers and by slightly more aggressive steps downward. Contingency science data acquisition during the third periapsis pass in the capture orbit and in the aerobraking periods was preserved.

After the spacecraft arrived at Mars on September 11th, it made one pass at an altitude of 250 km in the cruise configuration. At the following pass, the spacecraft's attitude was changed to point the science instruments at the planet in order to acquire initial science data. All the instruments operated perfectly. All instruments except the Laser Altimeter were left powered on to continue to take data after each periapsis drag pass during the first half of the four month aerobraking period.

### INITIAL AEROBRAKING

Aerobraking began on the third orbit and continued successfully, with a small interlude to correct an attitude pointing problem, until the MGS's 15th orbit of Mars when the atmospheric density increased dramatically (as it was expected it might) and the -Y solar panel behaved in an unexpected manner. Aerobraking was continued for three more orbits until it was determined that the solar panel motion might be an indication that there was not a full understand the damage done to it during its abnormal deployment just after launch when the level arm had become trapped in the hinge joint.

On Tuesday, October 1, 1997 at MGS's 12<sup>th</sup> periapsis, the -Y solar panel moved about 14 degrees toward its latched position with an applied dynamic pressure of  $0.45 \text{ N/m}^2$ . The telemetry potentiometer that indicates the panel position, which was assumed to be disconnected from the panel and had read anomalously since launch, moved in the opposite of the expected direction. This was a clear indication that the extent of the damage to the panel from the abnormal deployment was not understood. In addition, the spacecraft's aerodynamic null attitude unexpectedly changed by 14 degrees.

To compound problems, on Monday, October 6<sup>th</sup> at MGS's 15<sup>th</sup> periapsis, the atmospheric density increased by 50% exerting a dynamic pressure of  $0.9 \text{ N/m}^2$  on the -Y panel. Panel position telemetry indicated that the hinge had moved 1 degree past the expected latch position. To reduce the pressure on the panel, an orbit change was made on Tuesday, October 7<sup>th</sup> at apoapsis 15 to move the periapsis altitude up from 110 km to 121 km.

On Saturday, October 11<sup>th</sup>, at periapsis 18, with a seeming low pressure of  $0.23 \text{ N/m}^2$ , a 3 degree deflection of panel was recorded and it

was observed that the natural frequency of panel continued to change.

Through all of these observations, the other solar panel, the +Y panel, exhibited normal, expected behavior.

Now it was clear that the performance of the spacecraft in aerobraking was significantly different than expected, and that continued aerobraking at the current intensity posed a grave risk for successful completion of the mission.

Thus, late on Saturday, October 11<sup>th</sup>, the decision was made to move the spacecraft's trajectory out of atmosphere and stop aerobraking so that the situation could be examined in greater detail. On Sunday, October 12<sup>th</sup>, at the 18<sup>th</sup> apoapsis, a propulsive maneuver was executed to move the periapsis altitude up from 121 km to 172 km and out of atmosphere. The orbital period had been reduced to 35 hours.

A two week hiatus from aerobraking was established to better understand the flight data and mission situation. A review of the analysis and decision for mission revision was scheduled for October 27<sup>th</sup>. The flight team was charged with finding an acceptable way to minimize stress on panel and resume aerobraking. It was recognized by all that stopping aerobraking for this length of time would make it impossible to establish the 2 PM descending node orbital condition for mapping. It was hoped that the mission design team and science experimenters could find other, perhaps equally as good, mission options.

### AEROBRAKING HIATUS

During the aerobraking hiatus, the Project's overarching strategy was driven by balancing 1) the strong desire to get the spacecraft into or nearly into the position in which it would fulfill the expected mission objectives, with 2) the need to protect the valuable asset at Mars for whatever capabilities it could offer for the maximum amount of time. At the beginning of the hiatus, it was not known what the expected lifetime of the spacecraft might be.

The Project team pursued four major objectives: a) to explore all available data (in-flight, ground test, and additional experts' advice) to characterize the apparent structural failure in the -Y panel area; b) to find the spacecraft configuration that would minimize the disturbance to the apparent structural failure; c)

to characterize the potential mapping orbit alternatives available and the spacecraft constraints that might be inherent in them; and, d) to explore the mission design that would get the current orbital state to the best science data acquisition state. The results from that work was to enable a decision about how and when to restart aerobraking to gather more diagnostic data and/or to complete the mission objectives. It was anticipated that the hiatus would last two to three weeks.

Based on the strong recommendation of the Project Science Group, the Project team maximized the science return from the spacecraft while in the aerobraking hiatus. This included the normal data acquisition from the Thermal Emission Spectrometer (TES) and the Magnetometer/Electron reflectometer (MAG/ER) throughout each orbit. Special attitude changes were added once each orbit to point the Mars Orbiter Camera (MOC) and Mars Orbiter Laser Altimeter (MOLA) at the planet's surface just as was done during the contingency science acquisition period at the third periapsis passage. The MOC and MOLA special pointing began at periapsis 20 on Tuesday, October 14th.

A very intense analysis and ground testing effort with the solar array qualification hardware enabled developing a failure model that indicated that the triangular "yoke" structure that connects the solar panel to the main spacecraft structure had probably cracked and the solar panel motion that was being observed during aerobraking was the result of the yoke flexing about the crack.

This then required that aerobraking could not put the same stress on the solar panel and the yoke as in the current strategy, and aerobraking would have to be done with less intensity. Less intense aerobraking would mean that the proper orbit conditions could not be obtained on the original mission schedule. That would be devastating to the science investigations which require lighting on the Martian surface equivalent to 2 PM in the afternoon.

### AEROBRAKING RESUMED

Following twenty six days of study, the Project decided to resume aerobraking on Friday, November 7th (the first anniversary of the MGS launch) with a step down into the atmosphere at apoapsis number 36 moving the spacecraft's periapsis altitude down to where an average dynamic pressure level of  $0.2 \text{ N/m}^2$  would be felt on the solar panels. This was about one

third of the pressure level that was to have been experienced during the main phase of the original aerobraking plan.

The analysis and tests indicated that a secondary failure occurred when the -Y solar panel deployed undamped after launch as a result of the damper arm breaking off. At that time and throughout cruise, only the result of the damper arm lodging in the panel's hinge point that preventing it from opening all the way was observed. It wasn't until the effects of the pressure of the Martian atmosphere on the panel were seen, that it was recognized that something else was wrong - that there was a secondary failure. The additional failure acted like another flexure point or hinge, that allowed the panel to deflect more than would have expected during high pressure drag passes. Although it is not known with certainty, it is possible that the panel moved to its fully open position and latched during periapsis passes 11 and 12.

It was determined that the risk was acceptable to continue with the mission because the additional flexibility was understood, and the Project would determine how much the yoke could flex, and limit that flexure before a catastrophic failure would occur.

The hypothesized failure was a crack or deformation on the bottom (opposite side from the solar cells) of the yoke near the metal fitting that connects the yoke to the actuator. The yoke is the triangular shaped structure that connects the solar panel to the gimbal actuators. It is made of an aluminum honeycomb with graphite epoxy face sheets. The face sheet was probably cracked or deformed in an area that was never designed to take the stress that the undamped deployment subjected it to and had become unbonded from the aluminum honeycomb beneath it. This allowed it to flex slightly, and thus the panel which is connected to it flexed also when the atmospheric pressure was applied.

The dynamic pressure level of  $0.2 \text{ N/m}^2$  was chosen as a safe level for the spacecraft because three drag passes had been experienced at that level before aerobraking was stopped, during which the panel returned to its original position after each pass (the deformation was still elastic), the natural frequency of the panel didn't change substantially, and its stiffness didn't change. The Project continued to carefully monitor the flexure as aerobraking continued, and put

procedures in place to stop aerobraking again if the flexure exceeded preset metrics.

After the second step down propulsive maneuver at apoapsis 39 on November 12<sup>th</sup>, a ground sequence software configuration management error caused the 0.2 m/s orbit velocity change maneuver to be executed twice. An additional maneuver was successfully executed before the next periapsis to bring the periapsis altitude back to planned point nullifying the extra maneuver.

Aerobraking at the new dynamic pressure level continued in a satisfactory manner. The preset criteria for monitoring the stress on the -Y solar panel were never violated. Science data was acquired by the MOC and MOLA when their field's of view were swept across the planet's surface as the spacecraft's attitude was being changed from the periapsis drag orientation to the solar array normal to the sun attitude used during all other portions of the orbit. MAG/ER and TES acquired data throughout each orbit. These observations were continued through early February when decreasing orbital periods limited playback time, and increasing solar eclipse time reduced the power available.

The dynamics of the Martian atmosphere were significantly greater than had been assumed. While they were rapidly assessed using the spacecraft's accelerometer data and the orbital variations resulting from the drag passes through the atmosphere, it was found that managing the aerobraking corridor (dynamic pressure and periapsis altitude) was a much more workforce intensive process than originally planned.

#### NEW MISSION DESIGN

Even though aerobraking was restarted, a determination of MGS's final mapping orbit had not been made. It was clear that aerobraking was required to achieve a more circular orbit to maximize the mission's science return. The science investigators were very desirous of achieving global coverage and it was very important for the Mars Exploration Program to have MGS in position over the southern polar area to support radio relay from the New Millennium microprobes and the Mars Polar Lander in late 1999.

The development of a new mission strategy was planned to take a several months. During that time, the Project verified that the spacecraft, which was very carefully optimized for the 2 PM

circular mapping orbit, could handle other orbital conditions during mapping.

A mission design was found that included continued aerobraking with an orbital period reduction to 11.6 hours, then a cessation of aerobraking for a period while Mars, with MGS's orbit remaining fixed in inertial space, continued on its path around the Sun. After approximately six months, aerobraking would be resumed with a target of reducing the orbital period to 2 hours with all the original mapping orbit parameters, except that the 2 PM equator crossing would be on the ascending (rather than descending) node on the sunlit side of the planet. A solution had been found that was compatible with the spacecraft's design capabilities, the science instrument capabilities, and which satisfied all of the mission's original requirements. However, it would take an additional year. The new mission design was approved by a Project wide review on February 25-26, 1998.

#### SCIENCE PHASING ORBIT PERIOD 1 AND SOLAR CONJUNCTION

Aerobraking continued on the new mission plan strategy with much success until March 27, 1998, when, according to the new mission plan, the first of the two Science Phasing Orbit periods began. During these periods, aerobraking was stopped and the periapsis altitude was raised out of the atmosphere to 170 km to allow the time required for Mars to move to the proper position in its orbit around the Sun so that a further resumption of aerobraking would achieve the proper orbital parameters for mapping. Also during this period, "bonus" science data would continue to be acquired by the MOC and MOLA at each periapsis passage, with MAG/ER and TES data acquired continuously.

During the month of April, the spacecraft's ground track fell quite near the Cydonia region in Mars' northern hemisphere. This area had become the center of much public controversy after the identification of a rock formation termed, the Face on Mars, during the Viking missions in 1976. Three very successful opportunities to image objects in this area were taken and the resulting public release of raw and enhanced images gained the mission considerable attention in the popular press. Although the lighting conditions were different than in the Viking images, the resolution of the images was much improved. Opportunities were also taken during April to image the two Viking landing

sites and the Mars Pathfinder landing site. The later observations were less successful due to cloud cover and the small size of the landers.

During May, MGS passed behind the Sun, and spacecraft operations were suspended for several days while communications with the spacecraft were impaired due to the influence of the Sun.

#### SCIENCE PHASING ORBIT PERIOD 2

Following the solar conjunction period, the second portion of the Science Phasing Orbit period was continued until September 13th. During June, the latitude of MGS's periapsis migrated over the north polar of Mars as the northern polar cap was reaching its maximum extent. This offered the MOLA an unprecedented opportunity to map the thickness of the ice cap. Science operations continued in the same manner as in Science Phasing Orbit period 1. During August, four opportunities to acquire altimetry, thermal spectra and images from the Martian moon Phobos were taken. These data exceeded all other missions' previous data in quality.

As the period drew to close, 1000 high resolution images, 4 million spectra, 196 altimetry traces, and 164 radio science occultations had been recorded by MGS since its arrival at Mars in 1997.

#### HIGH GAIN ANTENNA DEPLOYMENT

As aerobraking and science phasing orbit operations were being conducted, the Project team was also studying an area of potential mission risk associated with the planned deployment of the spacecraft's high gain antenna just prior to the beginning of mapping in March 1999.

The High Gain Antenna (HGA) on MGS is currently in its stowed (or launch position). It has never been deployed, although it is constantly used for communications when the spacecraft is oriented to point it to Earth as it is in most parts of the current science phasing and aerobraking orbits.

The HGA cannot be deployed until after the last use of the spacecraft's main engine. Otherwise, the HGA in its deployed position would be in the plume of the main engine and would be damaged by any use of the engine. The last planned use of the main engine is for the propulsive event at will terminate the last phase

of aerobraking and place the spacecraft in the mapping orbit in March 1999.

The HGA will be deployed on the end of a 2 m (6.6 foot) boom. The HGA would be released from its stowed position on the side of the spacecraft and move through about 180 degrees of arc to its final position with its speed of motion controlled by a device called a rate damper.

The Mars Polar Lander spacecraft, scheduled for launch in January 1999, uses a similar rate damper device to control the speed of the deployment of its solar arrays.

The MGS spacecraft also used these devices to control the rate of deployment of its solar arrays. (On MGS, the shaft of the rate damper on the -Y solar array failed during deployment. The resulting stress from the undamped deployment caused the damage to the solar array yoke structure that has required less aggressive aerobraking.)

Testing of the Mars Polar Lander revealed the situation that the rate damper will allow a large amount of motion before the rate limiting or damping becomes effective. This is the result of gas bubbles that come out of solution in the damper's working fluid after tens of days in the vacuum of space.

If there is a significant amount of motion before the damping starts, a large amount of stress (force) is felt in the structure being deployed. This stress (force) can be accommodated by the solar structure and the damper (because it was manufactured with a stronger material than MGS's) in the Mars Polar Lander.

If the shaft of the damper broke at the onset of damping and the HGA and its boom continued to move without its speed being limited, the resulting forces at the completion of its travel would be sufficient to rip the boom's hinge out of the spacecraft deck essentially separating the HGA from the spacecraft. Although there are additional low gain antennas on the spacecraft bus structure, one might think that the loss of the HGA would only slow data return to Earth. However, the spacecraft radio's transmitter (power amplifiers) are located in a compartment on the back side of the HGA dish, so a loss of the HGA also means a loss of all transmitting capability from the spacecraft and thus the catastrophic end of its mission.

A detailed analysis of the strength of the HGA structural elements has been completed. In addition, an analytical model that predicts the stress in these elements as the result of a delay in the onset of damping has been generated. It shows that the only component of concern is the shaft of the damper. In the shaft, the margin of strength is about 75%.

It is clear that a potentially mission catastrophic situation can be avoided by never deploying the HGA. This, however, violates a basic tenant of the MGS mission which is that science data can be acquired continually. If the HGA remains in its stowed, or undeployed position, it will always be pointing at a right angle to the pointing direction of the science instruments and cannot be articulated to point continuously at Earth. Thus, science instrument pointing at Mars (science data acquisition) and HGA pointing at Earth become mutually exclusive events, i.e., they cannot be done at the same time.

Leaving the HGA in a fixed point was studied during the spacecraft design period very early in the Project life cycle as a means of cost savings. At that time, it was determined that the sequence of pointing the science instruments at the planet, then, after the spacecraft's recorders were filled, turning the spacecraft to point the HGA at Earth was a feasible mode of operation, but it significantly reduced the amount of science data that could be returned from Mars in a given period of time and was discarded.

The Project is currently evaluating its options. It is possible for MGS to assure that it will meet its minimum success criteria (Acquire globally distributed data sets, from at least three of the four science instruments within the range of the instruments (<500 km above the surface), for a minimum of 30 days in the mapping orbit or for an equivalent integrated time in an unknown elliptical orbit; carry out the science objectives defined for these data sets; and distribute their results to the science community within six months of acquisition) by using the alternating science acquisition then turn to playback mode, but extended operations in that mode would extend the mapping mission duration by years and contribute to a substantial operations cost increase in order to meet the MGS mission's full success criteria.

A decision on the deployment of the HGA on the new mission plan schedule will be made at the MGS Mapping Readiness Review on

February 3, 1999. If the decision is made not to deploy the HGA on the new mission plan schedule, then the question will be re-addressed after the minimum success criteria have been met and/or after the support periods for microprobe and Mars Polar Lander missions have been fulfilled.

## BEGINNING AEROBRAKING PHASE 2

The Project conducted a Readiness Review to establish that the spacecraft, and all the people and processes were ready to begin aerobraking phase 2. The lessons of the first phase were evaluated and certain process changes were introduced to yield easier and more reliable aerobraking operations management. The Readiness Review found that Project was ready. Aerobraking operations were scheduled to start on Monday, September 14, 1998, with a 12 m/s propulsive maneuver to perform the first step of lowering the periapsis down into the atmosphere again. Two additional maneuvers of lesser magnitude would complete the walk-in to the correct aerobraking altitude.

Before the spacecraft's main engine could be utilized for the first maneuver, its fuel tank needed to be repressurized to assure the proper fuel - oxidizer mixture. During the repressurization activity on September 9th, a previously unobserved performance attribute of the backup uplink command path in the spacecraft was encountered. The Project decided to delay the aerobraking maneuver by three days until the telecommunications system performance had been revalidated.

As several sequence modifications had been made to refine the aerobraking process since phase 1, spacecraft was programmed to perform a rehearsal of its drag sequence at the periapsis just preceding the first propulsive maneuver, then scheduled for September 17th. Following this rehearsal, the +Y solar panel didn't return to proper sun pointing position. Since not enough power was being generated to fully supply the spacecraft's needs, the spacecraft's two nickel hydrogen batteries were discharged. When the state of charge of the batteries reach a critical level, the spacecraft's on-board fault protection software aborted the maneuver sequence and put the spacecraft into a safe and stable state designed to assure solar power generation and communications with Earth. The cause of the improper solar array pointing was traced to a typographical error in the ground software used

to generate the spacecraft's sequence that went undetected.

At this writing, the spacecraft's hardware and software configurations are being restored to their normal state in preparation for another attempt at the resumption of aerobraking on September 23<sup>rd</sup>. The delays encountered in the resumption of aerobraking phase 2 are readily accommodated in the aerobraking performance margins. Aerobraking during this period will be less aggressive (lower average dynamic pressure), by design, than during the first phase of aerobraking. More than 800 orbits remain until aerobraking will be completed.

### SCIENCE RESULTS

MGS has been enormously successful during its first (and extra) year at Mars. All of the instruments are performing well, and the operations processes have been successful at retrieving the data acquired. These observations are made all the more remarkable because the spacecraft and its instruments are not operating in the thermal or pointing environment for which they were designed. Science results have been reported at several major scientific meetings, in the journal Science (March 1998), on the Project's World Wide Web site (<http://mars.jpl.nasa.gov>) and in the popular media.

Initial results have identified remnant surface magnetic fields rather than a central dipole field like the Earth's. The lifecycle of a regional southern hemisphere dust storm was observed. The extent of the northern polar cap was mapped. An observation of the mineral hematite, typically associated with hydrothermal activity on Earth, was made near the Martian equator. Altimetry data indicate that the northern plains are extremely flat. Hazy, clouds and fog have been observed that are characteristic atmospheric phenomena of the northern hemisphere winter. Among the highlights of the past year's imaging observations are the occurrence of thousands of meters of layered materials in the walls of the Valles Marineris, evidence of sustained flow within some reaches of Martian valley systems, suspected evidence of seepage and ponding, and the discovery of dunes of a variety of shapes and brightnesses that suggest different compositions and particle sizes or shapes. Data acquired from the observations of Phobos suggest the surface is covered in a meter thick blanket of very fine particles. An atmospheric density model been

established that shows increased density in two locations 180 degrees of longitude apart.

### SUMMARY

MGS has concluded its first year at Mars with the collection of a set of "bonus" science data that includes a tantalizing look at Mars that foreshadows the more detailed examination that will be forth coming as mapping begins in 1999. Its first year has experienced the discovery of more extensive initial solar array deployment damage than assumed requiring a revision of aerobraking strategies and a revision of its mission plan. Evaluation of potential risks associated with potential hardware failure during its high gain antenna deployment may require additional modification to the mission plan.

Overall, MGS and its Earth based operations crew have performed very well during its first year at Mars. The spacecraft and its science instruments are operating very well with the only degradation observed to date (other than the damage in the -Y solar panel yoke which occurred during the immediate post-launch deployment) in one gyro spin motor in the spacecraft and in a reference lamp in the TES instrument.

Aerobraking, while operationally intense, has been extremely successful in reshaping MGS's orbit.

MGS is nearing beginning of its two-year mapping period that will unlock new secrets of the Red Planet.

### ACKNOWLEDGMENTS

The work described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, and by its industrial partner, Lockheed Martin Astronautics, under contract to the National Aeronautics and Space Administration.

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